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DEVELOPMENTS IN THE PRODUCTION, CASTING AND FABRICATION OF IRON AND STEEL IN RELATION TO SMALL TONNAGE STEEL PLANTS

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DEVELOPMENTS IN THE PRODUCTION, CASTING AND FABRICATION OF IRON AND STEEL IN RELATION TO SMALL TONNAGE STEEL PLANTS

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1. Introduction

(a) A close link between the economic development of a country and its steel consumption is well known[1]. Consequently, it is believed that the first efforts of less-industrialized countries should be aimed at developing iron and steel production for industrialization, an indispensable factor for social and hum progress.

(b) It is known that the majority of the under-industrialized countries are not able to obtain the steel tonnages which they require, but rather only the quantity which their capacity to import permits. One of the obstacles to the development of the steel industry in these countries is the general shortage of capital, which is of considerable consequence since development of a steel industry requires large investments. Capital is not the only scarce factor for industrially emerging regions. In many countries, the availability of foreign exchange to pay for imports represents a similar or even worse problem. It is, however, important to bear in mind that domestic production, even on a small scale, could well save a substantial percentage of the foreign exchange necessary to cover the delivered cost of imported steel.

2. Market-Size and Steel Works Capacity

(a) One of the most important factors in determining the capacity of a new steel industry is knowledge of the size of the market. It has been a common practice to estimate market demand on data, in most cases scanty, for the immediately preceding years. This method may lead to underestimation of the market in cases where unsatisfied demand existed because of limitations in the capacity to import. The main objective is to adjust the steel mill capacity to the dimensions of the market leaving room for future expansions. The capacity of a steel works has a prime influence upon production costs. In general, steel works with lower assembly costs (i.e., mining cost of raw materials plus haulage costs to the plant) and wage rates are in a more favourable position to face competition; that is, the minimum size will be smaller. The size of operation is also governed by other factors which influence costs. Among those of major importance may be mentioned the composition of raw materials, the distance of the plant from local markets, and so forth.

(b) Installation of an integrated steel plant based on classical production processes, including the reduction of iron ores by coke in blast furnaces, can be justified on economic grounds if the market demand of steel products is above a certain minimum.

Although the actual capital cost figures are difficult to give, it appears that blast furnace plants, including all auxiliaries, may cost from $60 to $90 per ton of pig iron annually[2], and a fully integrated steel works may cost in the order of $350 to $600 per ingot-ton of annual capacity, depending on the product mix, the capacity of the plant and its location.

(c) In addition to the excessive initial investment involved, a blast furnace unit lacks the flexibility of operation that must be reckoned as one of the requirements in less-industrialized countries where the market is small, say, less than 300,000 tpy. It appears that consideration should therefore be given to the many methods of iron ore reduction other than classical blast furnace since, in general, they need smaller investments, have greater flexibility of operation and employ a larger proportion of man power. In addition, they do not require good metallurgical coking coal. Among these methods, the following are the most important: electric iron smelting, low-shaft smelting, and numerous so-called direct reduction or direct iron methods, which produce in some instances a high grade product equivalent to scrap and in others some variety of pig iron with special characteristics.

(d) Figure I gives a general classification[3] of the various methods of making iron. It will be seen that there are a large number of direct reduction methods in various stages of development. There is no doubt that large coke-fired blast furnaces will continue to be the major producers of pig iron in areas where markets are large and metallurgical coke is available. The purpose of this paper is to examine briefly the scope of direct reduction and other non-conventional processes for the establishment of smaller steel plants in regions where the potential market is limited and the coking coals are not easily available. These small plants could meet a part of the regional demands and open the door to a variety of processing industries, which in turn would further accelerate the industrial development of the region.

(e) As stated earlier the direct iron processes are in different stages of development. Some are in commercial operation while others are in an advanced planning stage and are ready for immediate installation. Others are in the experimental stage, e.g., the SL direct reduction process[25] recently developed in Canada. Since a voluminous literature on these processes is available, only the few that have operated successfully as production processes will be described. There is no intention to imply superiority of one process over another. The choice, as stated earlier, will be made on the basis of the types and costs of fuel and energy available, capital costs/annual ton of capacity, market size, quality, quantity and type of ore, etc.

3. The Wiberg-Soderfors Process:

(a) The Wiberg method of manufacturing sponge iron has a long record of successful operation in several Swedish steel plants, the first industrial size unit being built in 1932.

(b) The ore must be in lump or pelletized form but the reducing atmosphere may be generated from coke or coal, or by cracking natural gas. Usually, the gas is produced from coke or coal in an elec-

trically heated carburetor. When coke is used as fuel, its sulphur content is largely gasified and occurs mainly as hydrogen sulphide in the gas. This sulphur is removed in a filter interposed between the carburetor and the furnace.

(c) According to one source[4] the estimated production cost in 1958, in a Swedish plant of 27,500 net tons annual capacity, was 280 Sw Cr per net ton of sponge iron (86% Fe), or about U.S. $53.70 per net ton. This is equivalent to about $62.46 per net ton iron in the sponge. The estimated cost was based on a total investment cost (excluding pelletizing plant) of $1.6 million.

4. HyL Process

(a) This direct iron ore reduction process has proven to be a commercial success. The process can be employed where scrap is either in short supply or expensive and where high grade ores (or concentrates) and cheap natural gas are available.

(b) The HyL process is a batch process in which rich lump ore is reduced in a retort by desulphurized hot reformed natural gas. This gas is passed through a fixed ore bed in the reactors for a period up to 4 hr. The ore, preheated to 850-1000°C (1500-1830°F), is 90% reduced to form sponge and is then stored hot or discharged directly to an electric melting furnace.

(c) Capital cost for a plant of the HyL type will vary according to local conditions. However, according to one estimate[5], HyL installations require about half of the capital investment required for a conventional blast furnace, including coke ovens, of the same capacity. The reported[6] capital investment for a 500 ton/day plant was estimated in 1958 at $30 per annual ton iron, and the operating cost was placed at about $10 per ton.

5. Krupp-Renn Process

(a) This process was developed over 25 years ago in Germany, and has probably enjoyed wider commercial application than any other direct reduction process. Basically, the Krupp-Renn process involves the continuous reduction of iron ore in a rotary kiln using coke breeze as a reducing agent and a pulverized fuel flame for heating. Gas or oil can also be used for heating. Reduction is not dependent on the use of lumpy metallurgical coke. A low-quality solid carbonaceous fuel can be employed to reduce a wider range of ores. This includes both low grade ores and ore fines. Furthermore, the process is amenable to siliceous ores. The mixture of gangue and metallic iron is discharged in a pasty condition and is known as "luppen" (nodules). Iron and slag are then separated by milling and magnetic separation. Sulphur pick-up from reducing material may present production problem.

(b) On the basis of published estimates[7,8], it appears that the investment cost of Krupp-Renn plant in 1958 was about $42 to $50 per annual ton of "luppen" containing 92-95%, and the cost of production was at DM200 ($45.75) per ton "luppen". In a more recent estimate Astier[9] gave a figure of 180 new French francs ($39.80) per ton of "luppen" made from siliceous ore of 30-33% Fe content.

I. Smelting	Shaft Furnaces	Conventional blast furnace; low shaft furnace (Demag-Humbolt)***
	Electric Furnaces	Tysland Hole*; Lubatti*; deSy Ghent***
	Electric Furnaces with Pre-reduction	Strategic-Udy***; Orcarb***; Dwight-Lloyd-McWane***
	Rotary kiln	Basset*
II. Flash Smelting		Flame Smelting (Cyclusteel)***; Jet Smelting***; Diamond Alkali
III. Direct Reduction gas reducant	Shaft Furnace	Wiberg-Soderfors; Lurgi Gafluser***
	Retort	Madaras***; Hyl*
	Fluid bed	Esso Little*; Nu-Iron***; Armco H-Iron***; Stelling***; Msgrigal
IV. Direct Reduction solid reducant		Tunnel kiln Hoganas-Sieurin*; Krupp-Renn; Bureau of Mines; R-N**; Bruckner*; Urquehart***

* Commercial. ** Semi Works. *** Pilot.

I. SMELTING

Class	Process Name	Principals	Description and Status
Shaft Furnaces	Conventional Blast Furnace		
	Demag-Humbolt		Low shaft furnace employs briquettes that include fuel, ore and limestone. Pilot plant 10-15 tpd has been run; new plant due with capacity of 100 tpd.
Electric Furnace	Tysland Hole	Elektro-kemisk	Conventional electric smelting; employs lump ore and electric arc; 100 furnaces in operation; 3-4 million tons capacity.
	Lubatti	Demag	Employs electric current through slag; commercial but not in wide use.
	deSy Ghent	U. of Ghent	Electric furnace with two components; pilot plant built.
Electric Furnace with pre-reduction	Elkem with pre-reduction kiln	Elektro-kemisk	Submerged arc furnace; pre-reduces and pre-heats ore in kiln.
	Strategic-Udy	Strategic-Koppers	Electric resistance and arc heating system; uses kiln for pre-reduction and pre-heating; 1000 kw semi-works plant in operation; letters of intent for two plants. One letter covers 300 tons day plant for Quebec South Shore Iron & Steel Co.
	Orcarb	Swindell-Dressler	Employs balls of fine ore and coking coal. This is heated, pre-reduced and passed through electric furnace. Pilot plant in Harmarville, Pa.
	Dwight-Lloyd-McWane	McDowell Co.	Pellets of fine coal and ore are passed into sintering machine; product goes to electric furnace.
Rotary Kiln	Basset	F. L. Smith Co.	Make liquid iron in kiln; commercial plants in Europe; an old process.

II. FLASH SMELTING

Process Name	Principals	Description and Status
Flame Smelting (Cyclosteel	British Iron & Steel Research Assn.	Pilot plant; makes iron, not steel.
Jet Smelting	Ontario Research	Natural gas and powdered ore mingled to produce iron; early pilot stage.
Diamond Alkali	Diamond Alkali Co.	Gas reactor for desulphurization of pig iron has been mentioned for possible application to iron making.

Others: Oster; Armco

III. DIRECT REDUCTION

(gas reductant solid product)

Class	Process Name	Principals	Description and Status
Shaft Furnace	Wiberg-Soderfors	Stora-Kopparberg	Coke or natural gas used as reducing agent; carbon fully oxidized to give high fuel efficiency.
	Shaft Furnace	Lurgi Gafluser	Pilot plant; no details.
Retort	Madaras	Madaras	Lump ore or pellets reduced by gas; pilot stage.
	Hyl, Hojalata y Lamina	M. W. Kellogg	Lump or agglomerated ore with reducing gas; 200 ton unit now operating; 500 ton plant coming.
Fluid bed	Esso Little	Esso Development Co., A. D. Little Co., Texas Co.	Pilot plant.
	Nu-Iron	U. S. Steel	Original 2 ton capacity pilot plant being refined.
	H-Iron	Hydrocarbon Research, Inc., Bethlehem Steel	Pilot plant built; second plant being built at Los Angeles with a capacity of 110 tons a day.
	Stelling	Stora-Kopparberg	Pilot plant.
	Others: Armco	Pilot plant.	

IV. DIRECT REDUCTION

(solid reducant solid product)

Process Name	Principals	Description and Status
Tunnel kiln	Hoganas Sieurin	Ore and coke heated in tunnel kiln; process long used in Sweden to produce high grade powdered iron. One plant in Riverton N. J.
Krupp-Renn	Fried Krupp Southwestern Engineering Co.	Kiln used to produce partially fused iron shot; applied to special ores. Thirty-five kilns have been built; many now inoperative.
Bureau of Mines	U. S. Bureau of Mines	Rotary kiln used to reduce coal, ore and limestone; semi-works plant was built. Project not active.
R-N	Republic Steel Corp., National Lead Co.	Kiln used to reduce ore and produce briquettes; can handle high phosphorous ores or high grade ores. Plant near Birmingham has capacity of 50 to 75 tons a day.
Bruckner	Kennecott Copper	Horizontal rotary kiln used to make sponge iron in connection with copper recovery; commercial.
Urquehart	Steel Processing Co. Fort Pitt Bridge Co.	Ore fines and carbon charged into inclined rotating tube; iron balls go after reduction; small test furnace.
Others: Freeman; Kalling Domnarfvet		

Figure I. General classification of the various methods of making iron[3].

6. R-N Process

(a) The Republic Steel-National Lead process employs a rotary kiln operating below fusion temperatures. Crushed and sized ore of a wide variety or balled fines are fed into the kiln along with the carbonaceous reducing agent. Limestone or dolomite is also fed to control the sulphur content of the ore and the reductant material. Coke breeze or char is used for reduction and for heating gas (methane) or oil. As the ore travels through the kiln, countercurrent to the flow of heat, it is dried, preheated and reduced. The discharged materials are separated by screening and by gravity and/or magnetic separation.

(b) Although more recent figures are not available, it may be interesting to point out that in 1958 the estimated capital cost of an R-N unit, with an annual capacity of 400,000 gross tons, was reported[10] at about $19.5 million, and the production cost was estimated at $43.20 per net ton of R-N briquettes containing approximately 80-90% metallic iron.

7. Submerged Arc Electric Smelter

(a) One of the most outstanding methods for reducing the requirement of metallurgical coking coal - at the same time making small scale ironmaking possible - is the electric smelting furnace[11]. Iron ore and carbon are reacted in an arc furnace to produce molten iron, slag and waste gas containing carbon monoxide and carbon dioxide in the ratio of about 5:1. Electric energy serves the purpose of heating while low grade carbonaceous material acts as a reducing agent. The electric furnace requires only one-half as much fuel/reductant per ton of iron as a blast furnace. However, electric smelting requires about 1850-2400 kWh of energy per ton of iron, and its commercial feasibility, therefore, depends on the availability of cheap power.

(b) In order to decrease power consumption considerable progress has been made in recent years in preheating and prereducing the burden in rotary or shaft kilns utilizing the by-product gas from the furnace, thus reducing the power requirement by almost 50%. In addition to some of the advantages outlined above, electric smelters operate efficiently in units with outputs as low as 100 tons per day.

(c) Estimated capital investment for an electric smelter (without preheating or prereduction auxiliaries) with a rated daily capacity of 800 tons of pig iron has been reported[4] at $60-$75 per annual ton.

8. Steelmaking and Remelting of Sponge Iron

(a) Steelmaking on a small or medium scale does not present the same problems as ironmaking. The basic oxygen or L-D converter process appears to be suitable for small scale conversion of pig iron to steel. Basically, the L-D process consists of blowing high purity oxygen (99-99.5%), vertically downward, through a water cooled lance, on the surface of molten iron in a closed bottom vessel lined with basic refractories. Scrap, iron ore or cold pig iron are added to regulate the heat. One of the advantages of the L-D process is the lower capital investment as compared with a conventional open-hearth

melting shop. In a recent study[12] in India it was shown that the capital cost of an L-D melt shop (including oxygen plant) was about 60% of the cost of an open-hearth plant of equivalent capacity, i.e., two-million ingot tonsper year. In terms of Canadian dollars the capital cost amounted to about $23.50 and $39.00 per ingot ton annually for L-D and open-hearth melt shops, respectively. These figures will be substantially higher for a smaller melt shop. It was also reported that the production cost of the L-D process was about Rs. 20 ($4.40) less per ingot ton than that of the open-hearth shop.

(b) A passing mention may also be made of the Savard-Lee bottom-blown converter process[13] developed recently in Canada. Instead of top lancing as in the L-D process, oxygen is injected at a high pressure into the bottom of the metal through a specially designed injector. It is claimed that the metal can be converted to steel without further refining in an arc furnace. The importance of electric arc furnaces for steelmaking, especially in countries with low cost electric power and adequate scrap supply, is known all over the world. Under favourable conditions of electric power and scrap supplies, electric furnaces produce steel at costs comparable with open-hearth furnaces. At the same time capital investment is appreciably lower, about 60% of the open-hearth. It must, however, be mentioned that in most of the under-industrialized regions the situation regarding power and scrap supplies is far from favourable. Till recently, one of the major drawbacks of electric furnaces for the production of plain carbon steels was that they are not effectively adapted to molten iron charges. However, recent studies have shown the feasibility of refining molten pig iron in the electric arc furnace, thus improving its economics and increasing its scope.

(c) This brings up the question of using direct reduced iron or sponge iron as a substitute for cold scrap. In fact, extensive work on the utilization of sponge iron for steelmaking has been carried out in the last ten years and very promising results have been reported. It is no secret that Sweden uses a greater tonnage of sponge iron per year than possibly any other country at the present time. Similarly, HyL sponge[5] has been in use for electric steelmaking in Mexico since 1958. Weaver[14], Farley[15], and Babcock[16] investigated the melting of R-N briquettes in electric furnaces and more recently Masi and Cannizzo[17] reported that direct reduced iron is a good component for the cold charge of electric furnaces and that it can be tolerated in open-hearth melting.

(d) Although considerable progress has been achieved in the technique of remelting sponge iron in electric furnaces, there are still a number of problems. For instance, it is generally known that the power consumption may be increased by 10-25% when sponge is substituted for steel scrap. In addition, the fluxing of a large percentage of gangue results in a very large slag volume in the electric arc furnace. According to Armstrong[4] the concentration and briquetting of the metallic fraction of the sponge would eliminate or reduce many of these problems but would add to both capital and operating costs.

(e) In addition to the use of direct reduced iron in electric steelmaking, investigations have also been carried out to utilize it as a melting stock in basic hot-blast cupolas. In a recent study[18]

in Germany it was shown that direct iron briquettes containing 88-91% metallic iron and 0.3-0.4% carbon can be successfully remelted in a hot-blast cupola with a capacity of 20 tons per hr. The liquid metal produced was suitable for open-hearth and L-D practice, and analysed 3.80-4.20% carbon and 0.02-0.04% sulphur. The conversion costs (excluding the cost of briquettes) compared favourably with 100% steel scrap melting, and approximated the attractive figure of DM 40.00 (U.S. $10.00) per metric ton of the liquid metal produced. It was, however, reported that coke consumption for the remelting of briquettes was slightly higher than the all scrap melting.

9. Basic Hot-Blast Cupola

(a) Suggestions have been made to integrate some of the direct reduction processes into foundries with a view to reducing their cost of iron and their dependence on outside source of pig iron and scrap. It appears that hot-blast cupolas for steel plants and for foundries have acquired enormous interest in recent years. It has been said that basic hot-blast cupolas may be one means of providing hot metal for steelmaking without the construction of additional blast furnaces, particularly for smaller plants when the relatively small investment cost for added capacity is considered.

(b) According to Harman[19] the combination of basic hot-blast cupola and oxygen converter or L-D plant ranks among the lowest in capital cost and production cost for ingot producing facilities. On the basis of published information the capital cost of a hot-blast cupola plant is placed at about $7 to $10 per ton of annual capacity, and the net cost of production is estimated in the order of $40 to $50 per net ton of liquid metal, depending on the cost of metallic and fuel charges.

(c) The cold-blast acid-lined cupola is still the most widely used melting furnace for cast iron and it seems that this situation will remain for many years yet, although the economic advantages of using heated blast will cause an increase in the number of such installations. One of the most widely used methods of regulating the carbon content of grey iron melted in a cold-blast cupola is to adjust the pig iron in the charge. Since this material is the most expensive component of the charge, newer techniques have been suggested[20] of controlling the final carbon content, particularly at the higher levels. The most successful answer to this problem is the carbon injection process. Briefly, the process consists of injecting fine particles of graphite or other carbonaceous material by a stream of relatively inert gas, such as nitrogen, through a graphite lance immersed in the liquid metal. Generally, the carbon pick-up depends on the feed rate and carbon recovery. Therefore, the major operating factor that affects carbon pick-up is the immersion depth, which acts on both components. One of the factors that tends to limit the application of the process is the increase in sulphur content as the pig iron charge is decreased. However, it has been suggested that simultaneous desulphurization and carbon injection may offer a solution to the problem.

(d) On the basis of long term tests in Canada it was estimated[20] that a saving of about $6.15 per net ton of metal charged can be realized.

10. Continuous Casting

(a) As a result of the great technical progress that has been made in recent years, it is now considered practicable to replace the orthodox stages of ingot mould casting, stripping, soaking pits, and primary rolling in small steel plants by the adoption of continuous casting[21]. By eliminating these production stages the investment cost of a steel plant can be appreciably reduced. There are a number of machines in various parts of the world that cast billets, blooms and slabs in continuous lengths on a commercial scale and several more are in the experimental stage or under construction.

(b) Advantages of the continuous casting process become apparent in making comparisons with conventional casting. The yield of metal is greatly increased. For instance, improvement of 10 to 12% in the overall yield of the primary rolled product from liquid metal has been reported[22]. Characteristic high surface quality of the continuous cast product has practically eliminated the need for surface conditioning. The other main advantage of the process is that the low capital investment makes it quite practical to locate plants to suit the market and to take advantage of favourable freight rates. These are some of the features that will be particularly attractive to less-industrialized regions where the production rates contemplated are not very high.

(c) The economics of investment and operating costs are difficult to give. However, the figures published[23] in 1957 indicate investment cost of approximately $17 per ton and about $7 per ton for machines having an annual capacity of 50,000 tons and 300,000 tons, respectively. These costs and the corresponding amortization are believed to be considerably lower than those prevailing in integrated steel works based on cogging and other primary mills. The cost increment would be in the order of 50-70% or more for a conventional plant, depending upon the location.

(d) According to one source[24] the net saving per ton of low carbon steel billets produced by continuous casting is estimated at about $8 - $10. This is equivalent to reducing billet costs by about 12%. On the basis of published information it appears that in works with outputs ranging from 50,000 tons to 300,000 tons per annum, continuous casting may replace conventional ingot casting, soaking pit and primary mill practice with an appreciable saving in investment and operational costs.

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821 E - Oct.1962 - 1,600